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APF with PI Controller Based Harmonic Reduction in Micro Grid Distribution System

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***Abstract:* -- In distribution systems, the nonlinear loads draws non-sinusoidal currents from the AC mains due to sudden increase or decrease of load and also affects the load harmonics and reactive power. It also produces excessive neutral currents that give smog in power systems. Due to the nonlinear features and fast switching of power electronic devicesmost pollution problems are created in power systems. The Shunt active power filter(SAPF)controlled PWM converters are based on currentand has seen as a most viable solution. So the harmonics and reactive power compensation is presented in this paper from 3P4W micro-grid distribution system by PI controlled shunt active power filter (SAPF). The technique used to generate desired compensation current extraction is based on offset command instantaneous currents distorted or voltage signals in the time domain because compensation time domainresponse is quick and it produces easy implementation and lower computational load than the frequency domain.The MATLAB/Simpower Systems tool has proved that the combined system inject maximum power and compensate the reactive power and harmonic current drawn by nonlinear loads.**

***Index Terms*— Voltage Disturbances, Nonlinear Loads, PCC, Power Quality, Shunt Active Power Filter (SAPF), PWM.**

I. INTRODUCTION

Distribution systems introduced the power pollution by the nonlinear loads such as transformers, computers, saturated coils and increases the sophisticated power electronic devices in delay use.

The power electronic devices create most of the pollution issues due to its nonlinear characteristics and fast switching also increases non-linearity problems like low system efficiency and poor power factor. It affects the other consumers. So to overcome these undesirable features the shunt passive filters, consist of tuned LC filters and high passive filters are used to suppress the harmonics. To improve the power factor the power capacitors are hired but they have some limitations of fixed compensation as large size and can also exile resonance conditions. Hence over the classical passive filters the active power filters are best alternative method which is used to compensate harmonics and reactive power condition of the non-linear loads.

Even when the load is highly nonlinear the shunt active power filter based on current controlled voltage source type PWM converter has proved to be effective. Based on sensing harmonics most of the active filters are developed. An instantaneous reactive volt-ampere compensator and harmonic suppressor is used without of voltage sensors but need complex hardware for current generator. However, the conventional PI controller was used for the generation of a reference current template but the PI controller requires precise linear mathematical models, which are difficult to gain and fails to perform adequately under parameter variations, nonlinearity, load disturbance, etc.

So in this the PI controlled shunt active power filter is implemented for the compensation of harmonics and reactive power nonlinear loads. The control scheme based on sensing line currents are used which is different from convention ones. The DC capacitor voltage is regulated to estimate the reference current from system. A design criterion is described for the selection of power circuit components. Both the control schemes are compared and investigated. A full simulation program of the control schemes is developed to predict the performance for different situations and simulink models also has been developed for different parameters and operating conditions.

II. POWER FILTER TOPOLOGIES

Depending on the system application or electrical problem the active power filters are implemented as shunt type, series type, or a combination of both shunt and series

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active filters. These filters are also joined with passive filters to generate hybrid power filters.

The shunt-connected active power filter shows the characteristics similar to STATCOM (reactive power compensator of power transmission system) when used with self-controlled dc bus. The shunt active power filters act as a current source and it injects harmonic compensating current of same magnitude as the load current harmonics but shifted in phase by 180° thus compensates load current harmonics.

The series-connected filter compensates voltage in unbalances and sags/swell from the ac supply and protects consumer from inadequate voltage quality so these are used for low-power applications. As a substitute to UPS these filters can also be used having very low cost as no energy storing element like battery is used. Moreover overall rating of components is smaller.

The series active filters work as hybrid filter topologies with passive LC filters and these are connected in parallel to the load then series active power filter operates as a harmonic isolator and forcing the load current harmonics to circulate mainly through the passive filter rather than the power distribution system. The advantage of this topology is that the rated power of the series active filter is a small fraction of the load kVA rating.

In series-shunt active filter the shunt active filter is located at the load side and used to compensate the load harmonics, reactive power, and load current unbalances. These series filter is at the source side and can act as a harmonic blocking filter. This series-shunt active filter topology is known has Unified Power Quality conditioner. The other advantage of this topology is it regulates the dc link capacitor voltage. The power supplied or absorbed by the shunt portion is the power required by the series compensator.

Multilevel inverters are based on hybrid AC filtersandrecently used for active filter topologies. Three phase four wire inverters are becoming popular for most inverter applications like machine drives and power factor compensators. The benefit of multilevel converters is that they decreases the harmonic content generated by the active filter because multilevel converters can produce more levels of voltage than other converters. This feature helps to reduce the harmonics generated by the filter. One more advantage is that they can reduce the voltage or current ratings of the semiconductors and the switching frequency requirements.

III. VOLTAGE SOURCE CONVERTERS

The active power filter topologies mostly use as voltage source converters. This topology, shown in Figure 1, converts a dc voltage into an ac voltage by appropriately gating the power semiconductor switches. A single pulse for each half cycle can be applied to synthesize an ac voltage. For these purposes most applications are required for dynamic performance, pulse width modulation is the most commonly used for active power filter. The PWM techniques are applied to control the VSI consist of chopping the dc bus voltage to produce an ac voltage of an arbitrary waveform.

Voltage source converters are preferred over current source converter because it has higher efficiency and lower initial cost than the current source converters. They are expanded in parallel to increase their combined rating and switching rate, if they are carefully controlled then individual switching times do not coincide.

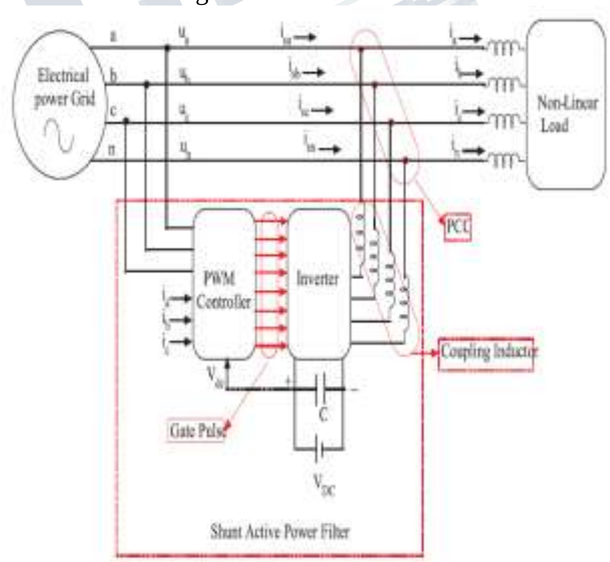

Fig.1 Shunt active power filters topology.

Therefore, higher-order harmonics can be eliminated by using converters without increasing individual converter switching rates. The nonlinear load current has harmonics, so that load current is the summation of fundamental harmonics and it integer multiple

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offundamental frequency. Then load current can be written as

$$i_L(t)=\sum_{n-1}^{\infty} i_n \sin(nwt+\emptyset_n)$$
$$=i_l \sin(wt+\emptyset_l)+\sum_{n=2}^{\infty}\sin(nwt+\emptyset_n) \quad (1)$$

Instantaneous Load can be written as

$$p_L(t)=v_s(t)\times i_L(t) \quad (2)$$

Putting value of $i_L(t)$from equation (1) in equation (2)

$$p_A(t)+p_R(t)+p_H(t) \quad (3)$$

Here$p_A(t)$ is active or fundamental power and $p_R(t)$ is reactive power. Harmonic power denoted by$p_H(t)$. So active or real power drawn by the load from the source is

$$p_A(t)=v_m i_1 sin^2wt\times cos\emptyset_1=v_S(t)\times i_S(t) \quad (4)$$

The source current after compensation is given by equation (5)

$$i_S(t)={p_A(t)}\Big/{v_S(t)}=i_1\cos\emptyset_1\times\sin wt=i_m\sin wt \quad (5)$$

Where $i_m=i_1\cos\emptyset_1$

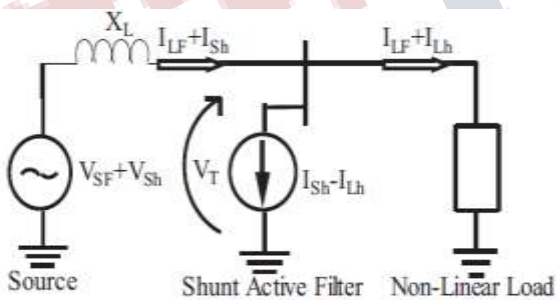

Fig.2 Principle of Shunt Current Compensation

In a practical converter, switching, conducting and capacitor leakage losses are produced. So that losses must be supplied by the supply or by the grid itself. So total current supplied by supply will be given as

$$i_{SP}=i_m+i_{slo} \quad (6)$$

wherei_{SP} = peak current supplied by source.

wherei_{slo} = loss current of converter supplied by the source.

If total harmonic and reactive power of the load isprovided by the Active Power Filter then there is no harmonic in source current and source current will be inphase with the source voltage. Therefore, the total sourcecurrent including losses will be assumed as$i_S^*(t)=i_{SP}\sin wt$.So compensating current will be given as

$$i_C(t)=i_L(t)-i_S^*(t) \quad (7)$$

For instantaneous compensation of reactive power in addition the harmonic power and source (grid) should be able to supply current$i_S^*(t)$.

IV. ESTIMATION OF REFERENCE SOURCECURRENT

The instantaneous currents can be written as

$$i_S(t)=i_l(t)-i_c(t) \quad (8)$$

Source voltage is given by

$$v_S(t)=v_m\sin wt \quad (9)$$

If a non-linear load is applied then the load current will have afundamental and harmonic components are represented as

$$i_L=\sum_{n-i}^{\infty} i_n\sin(nwt+\emptyset_n)$$
$$=I_n\sin(nwt+\emptyset_n)+\sum_{n-2}^{\infty}\sin(nwt+\emptyset_n) \quad (10)$$

The instantaneous load power can be given as

$$P_L(t)=v_S(t)\times i_l(t)$$
$$=V_m I_1 sin^2wt\times\cos\emptyset_1+v_m I_1\sin wt\times\cos wt\times$$
$$\sin\emptyset 1+Vm\sin wt\times n-2\infty In\sin nwt+\emptyset n \quad (11)$$

$$=P_f(t)+P_r(t)+P_h(t) \quad (12)$$

From (11), the real (fundamental) power drawn by the load is

$$P_f(t)=V_m I_1 sin^2wt\times\cos\emptyset_1=v_{S(t)}\times i_S(t) \quad (13)$$

From (13), the source current supplied by the source, after Compensation is

$i_S(t) = P_f(t)/v_S(t) = I_1 \cos\emptyset_1 \sin wt = I_m \sin wt$
Where $I_{SM} = I_l \cos\emptyset_1$.

Due to some switching losses in the PWM converter, the utility must supply a small overhead for the capacitor leakage, converter switching losses and real power of the load. The total peak current supplied by the source is therefore

$$I_{sp} = I_{sm} + I_{S1} \qquad (14)$$

If active filter offers the total reactive and harmonic power, then $i_s(t)$ will be in phase with the utility voltage and sinusoidal. At this time, the active filter must run the following compensation current

$$i_c(t) = i_L(t) - i_S(t) \qquad (15)$$

Hence, for accurate and instantaneous compensation of reactive and harmonic power it is necessary to estimate the fundamental component of the load current *as* the reference current. The design of the power circuit includes three main parameters: L_c ,$V_{dc,,ref}$ and C_{dc}.

A.SELECTION OF L_c ,V_{dc},ref and C_{dc}

The design of these components is based on the following assumptions:

- The AC source voltage is sinusoidal.
- To design of Lc, the AC side line current distortion isassumed to be 5%.
- Fixed capability of reactive power compensation ofthe active filter.
- The PWM converter is assumed to operate in thelinear modulation mode (i.e. 0≤max≤1).

As per the compensation principle, the active filter corrects the current i_{c1}. If the active filter compensates all the fundamental reactive power of the load, i_{s1} will be in phase and i_{c1} should be orthogonal to V_s.The three-phase reactive power delivered from the active filter can be calculated from a vector diagram.

$$Q_{C1} = 3V_S I_{C1} = \frac{3V_S V_{C1}}{wL_c\left(1-\left(\frac{V_S}{V_{C1}}\right)\right)} \qquad (16)$$

When $V_{c1} > V_s$. If PWM converter is supposed to operate in the linear modulation mode (i.e. $0 \le m_a \le 1$), the amplitude modulation factor m_a is

$$m_a = v_m/(V_{dc}/2)$$

Where $V_m = \sqrt{2}\, V_c$, and hence $V_{dc} = 2\sqrt{2}\, V_{c1}$ for $m_a = 1$.

The filter inductor L_c is also used to filter the ripples of the converter current, thenthe design of L_c is based on the principle of harmonic current reduction. The ripple current ofthe PWM converter can be given in terms of the maximumharmonic voltage, which occurs at the frequency $m_f\omega$

$$I_{ch(mfw)} = \frac{V_{ch(mfw)}}{m_f w L_c} \qquad (17)$$

By solving (16) and (17) simultaneously, the value of $L_c$and V_{c1} (i.e.V_{dc}*)* be calculated. V_{c1}, V_{dcref}, must be set according to the capacity requirement of the system (i.e. $Vs \le V_{c1} \le 2Vs$). As the switching frequency is not fixed with the hysteresis controller, a practically feasible value of 10 kHz hasbeen assumed. The selection of C_{dc}can be governed by reducing the voltage ripple. As per thespecification of the peak to peak voltage ripple and rated filter current ($I_{c1,rated}$), the DC side capacitor C_{dc} canbe found from equation

$$C_{dc} = \frac{\Pi \times I_{C1,rated}}{\sqrt{3} w V_{dc,p-p(max)}} \qquad (18)$$

V. PI CONTROL SCHEME

The error signal is fed to PI controller. The output of PIcontroller has considered as peak value of the reference current. It is multiplied by the component sine vectors in phase with the basis voltages to gain the reference currents. These currents are given to a hysteresis based, carrier less PWM current controller to generate switching signals of the PWM converter.

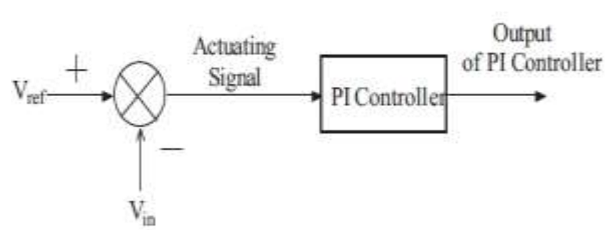

Fig.3 APF Control scheme with PI controller.

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The difference of reference current model and actual current chooses the operation of switches. These switching signals after correct isolation and amplification are agreed to the switching devices. Due to these switching actions current flows over the filter inductor Lc, to reward the harmonic current and reactive power of the load, so that active power drawn from the source.

VI. SIMULATION VALIDATION

The shunt active power filter modal is recognized and simulate in MATLAB with PWM based PI controller. The complete active power filter is composed mainly of three-phase source, a non-linear load, a voltage source PWM converter, and a PI controller. These components are modeled separately, integrated and then solved to simulate the system. A load with highly nonlinear characteristics is considered for the load compensation at PCC. The THD in the load current is 28.05%.

The compensator is switched ON at t=0.05s and the integral time square error performance index use the coefficients of PI controller. The optimum values of K_p and K_i are found to be 0.5 and 10, which relates to the minimum value of ITSE. Compensating currents of PI controllers are shown in 6. The DC side capacitor voltage during switch on response in figure 7 with PI controller.

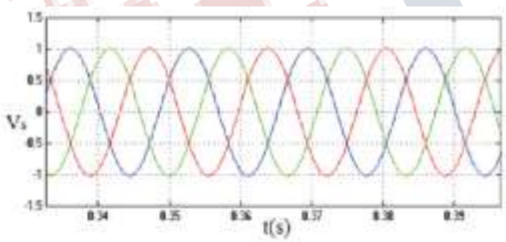

Fig.4 Source Voltage (p.u) Waveforms of the System

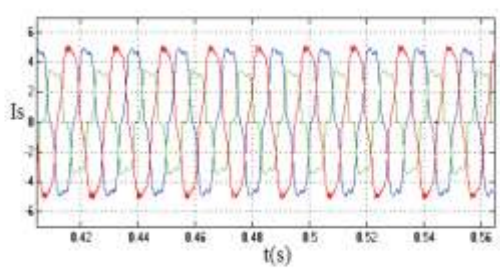

Fig.5 Source Current when the Compensator is not connected

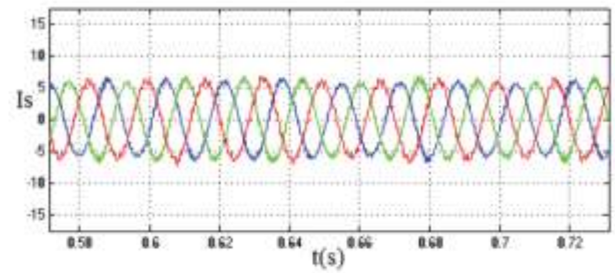

Fig.6 Compensating Current of PI Controller

From the wave forms it is clear that harmonic distortion is reduced after connecting compensator. The system parameters selected for simulation study are given in table 2 and 3. Figures 8-12 shows the simulation results of the implemented system with PI controller. The source voltage waveform of the reference phase only is shown in figure 4. A diode rectifier with R-L load is taken as non-linear load. The THD of the load current is 24.90%. The optimum values (Kp and Ki) are found to be 0.5 and 10 respectively.

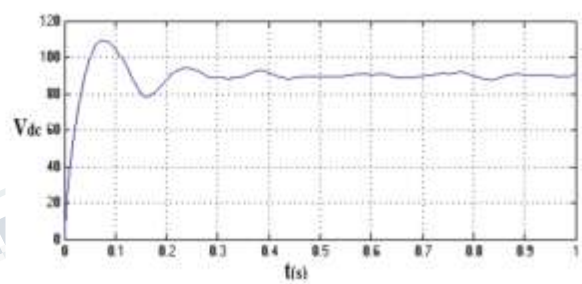

Fig.7 DC Capacitor Voltage during Switch-on Response with PI Controller

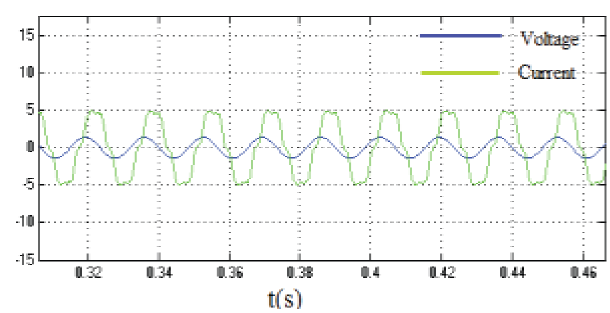

Fig.8 Phase difference between Source Voltage and Current without Compensation

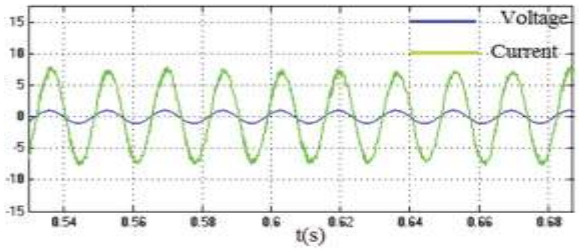

Fig.9 Voltage and Current are in Phase Using PI Controller.

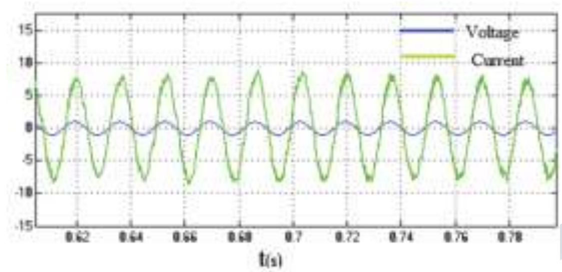

Fig.10 Power Factor Improvement Using PI Controller

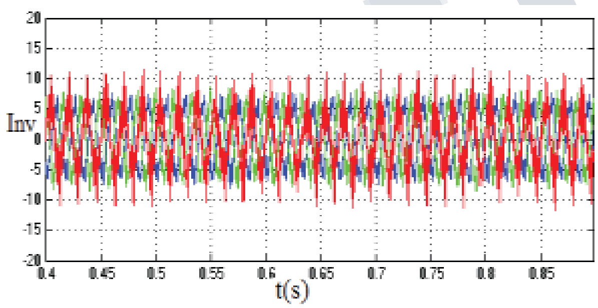

Fig.11 Inverter Currents using PI Controller

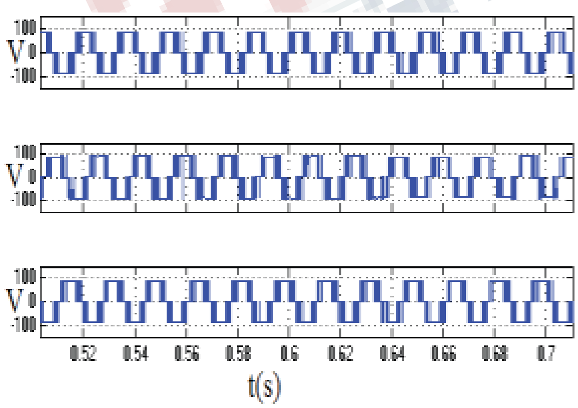

Fig.12 Three phase Voltage Generated by APF.

The settling time required by the PI controller is approximately 8 cycles. The source current THD is reduced near to 4% with PI compensation which is below IEEE standard with both the controllers.

VII. CONCLUSION

PI controller based shunt active power filter simulated in MATLAB are implemented for harmonic and reactive power compensation of the non-linear load at PCC. It is found from the simulation results that shunt active power filter improves power quality of the distribution system by eliminating harmonics and reactive power compensation of non-linear load. It is found from simulation results that shunt active power filter improves power quality of the power system by eliminating harmonics and reactive current of the load current, which makes the load current sinusoidal and in phase with the source voltage. The THD of thesource current is below 5% according to simulation result and it is in permissible limit of IEEE standard.

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